Loop-Induced Modifications to the Higgs Couplings

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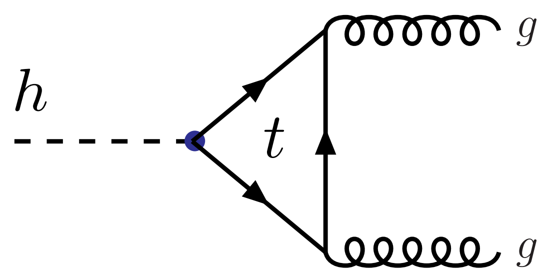
Basic questions:

- Why worry about loop-induced couplings? Naturalness!
- Precision of LHC vs. future facility
- Can (loop-induced) Higgs coupling measurements probe new states beyond direct reach of LHC? Yes!
- How much sensitivity does a future facility buy?

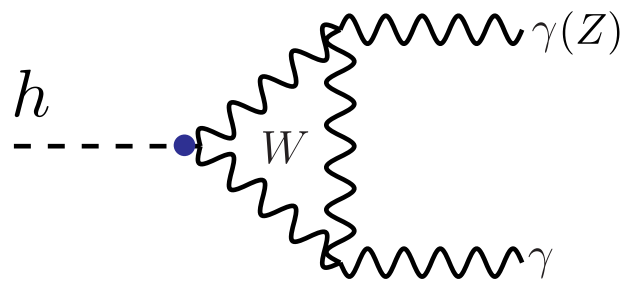
See also talks by T. Han and I. Low at Princeton Higgs Snowmass Workshop

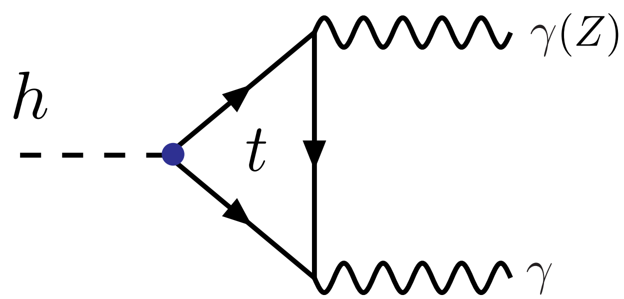
http://physics.princeton.edu/indico/conferenceDisplay.py?confId=127

Loop-induced Higgs couplings in the Standard Model



$$\sim \frac{\alpha_s}{12\pi v} h\, G^a_{\mu\nu} G^{\mu\nu a}$$

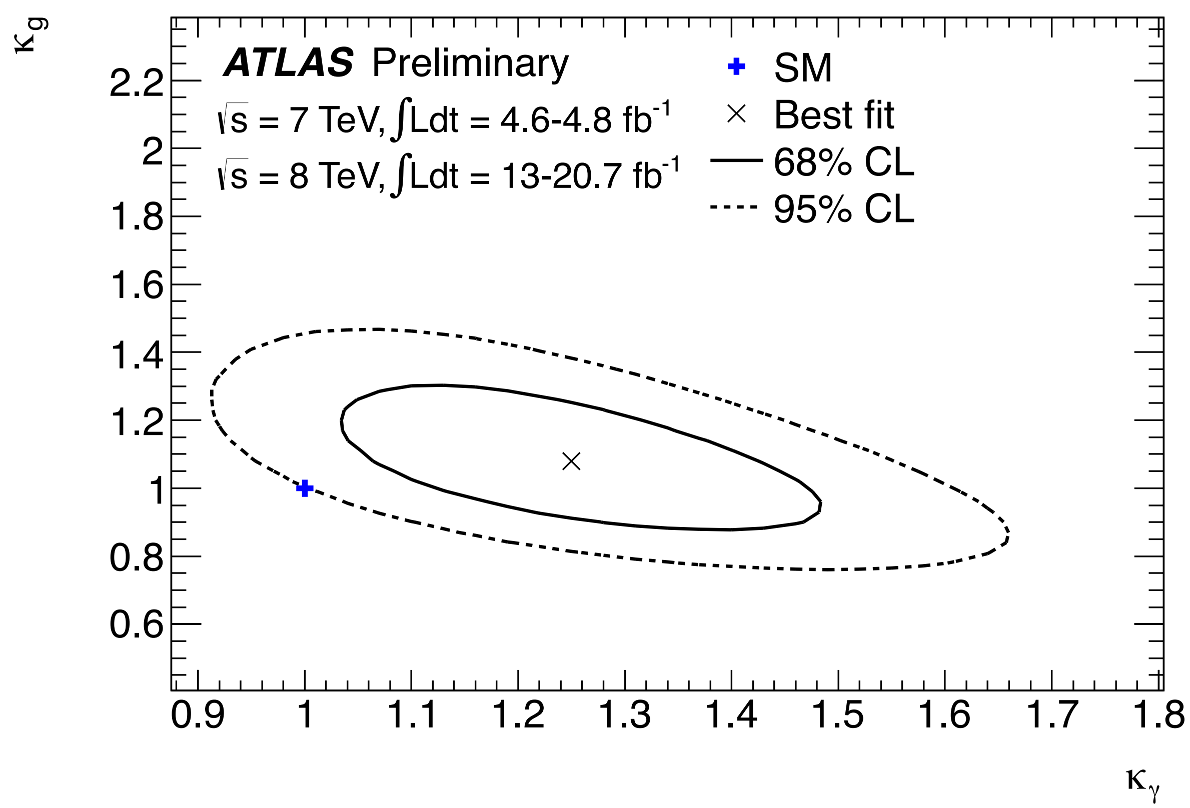


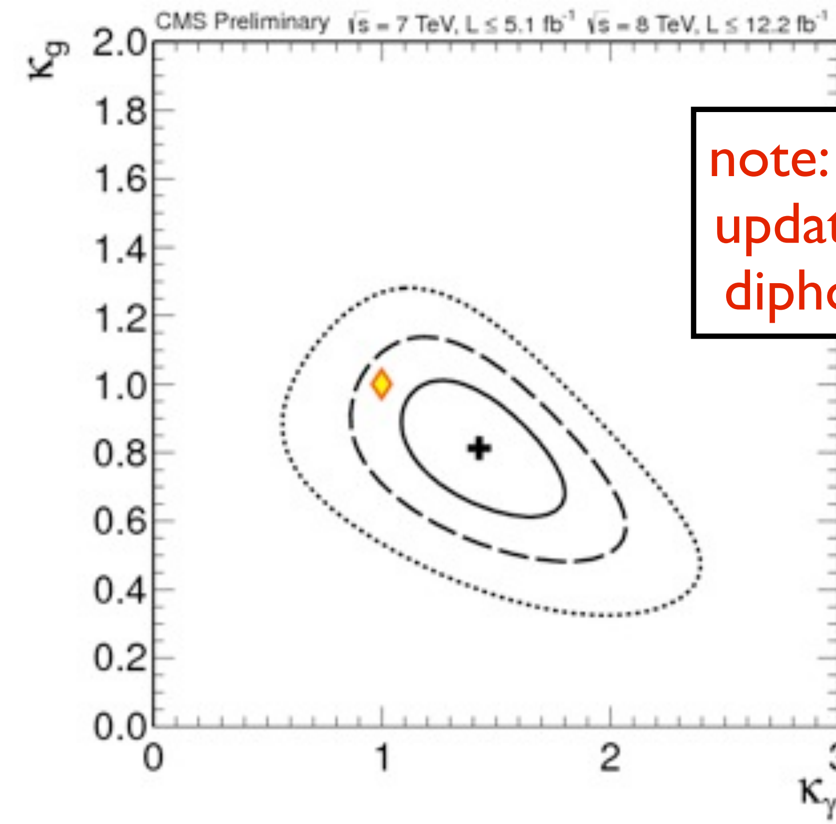


$$\sim \frac{\alpha}{8\pi v}[-8.3 + 1.4]\, h\, F_{\mu\nu} F^{\mu\nu}$$

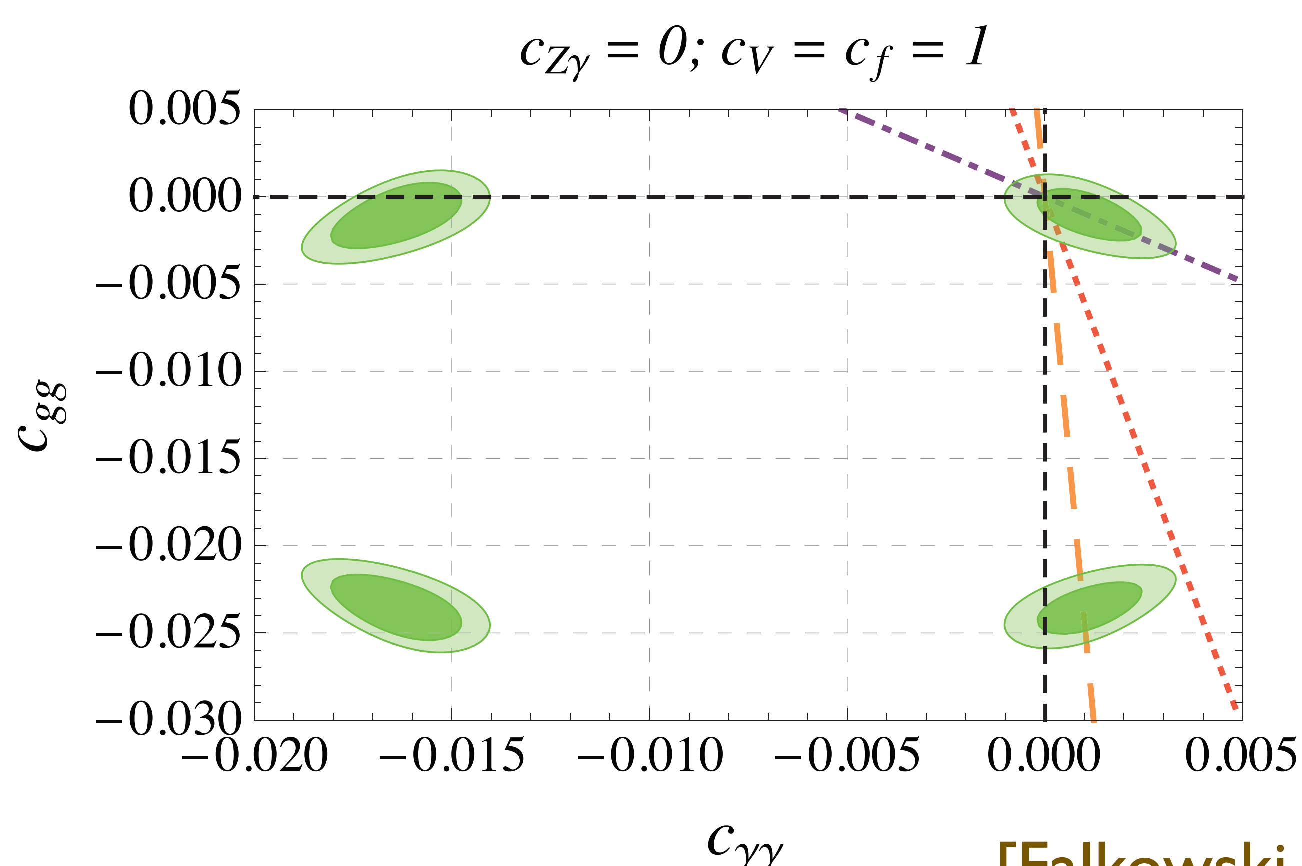
- Dominant production mechanism at LHC!
- Most sensitive search channel for 125 GeV Higgs
- Very susceptible to New Physics!

Status of $hgg, h\gamma\gamma$



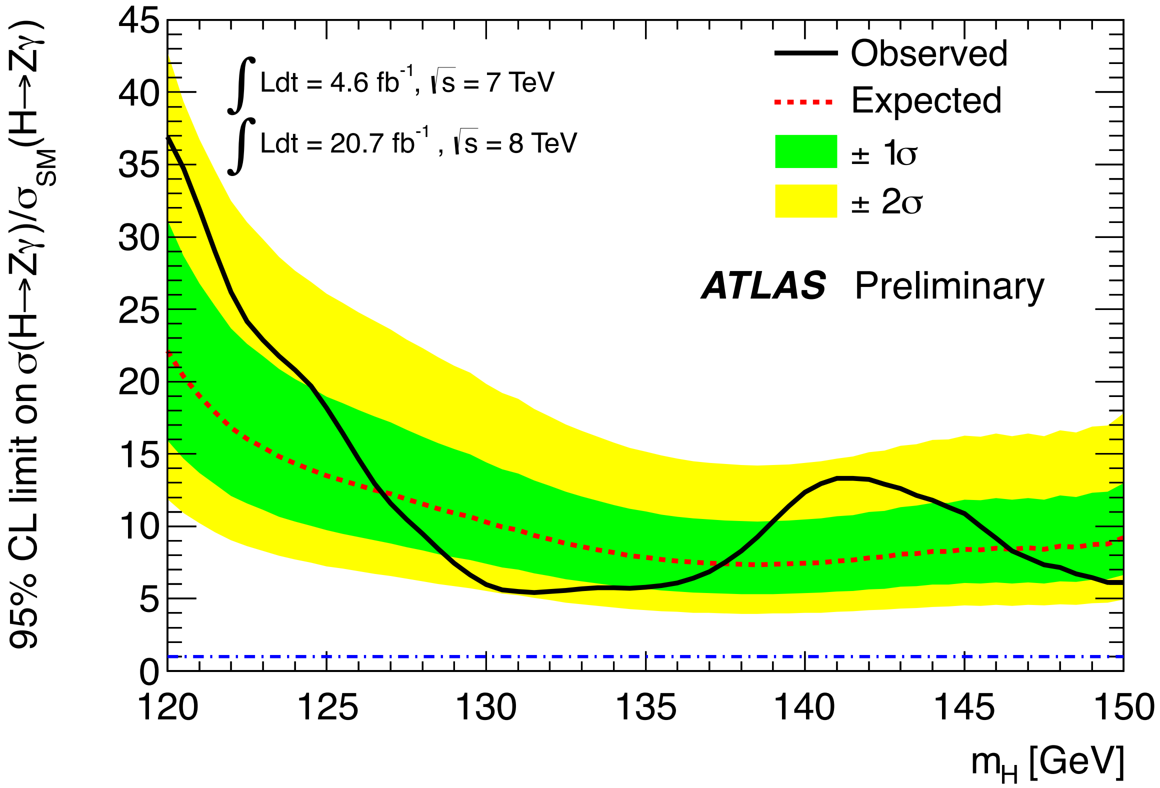


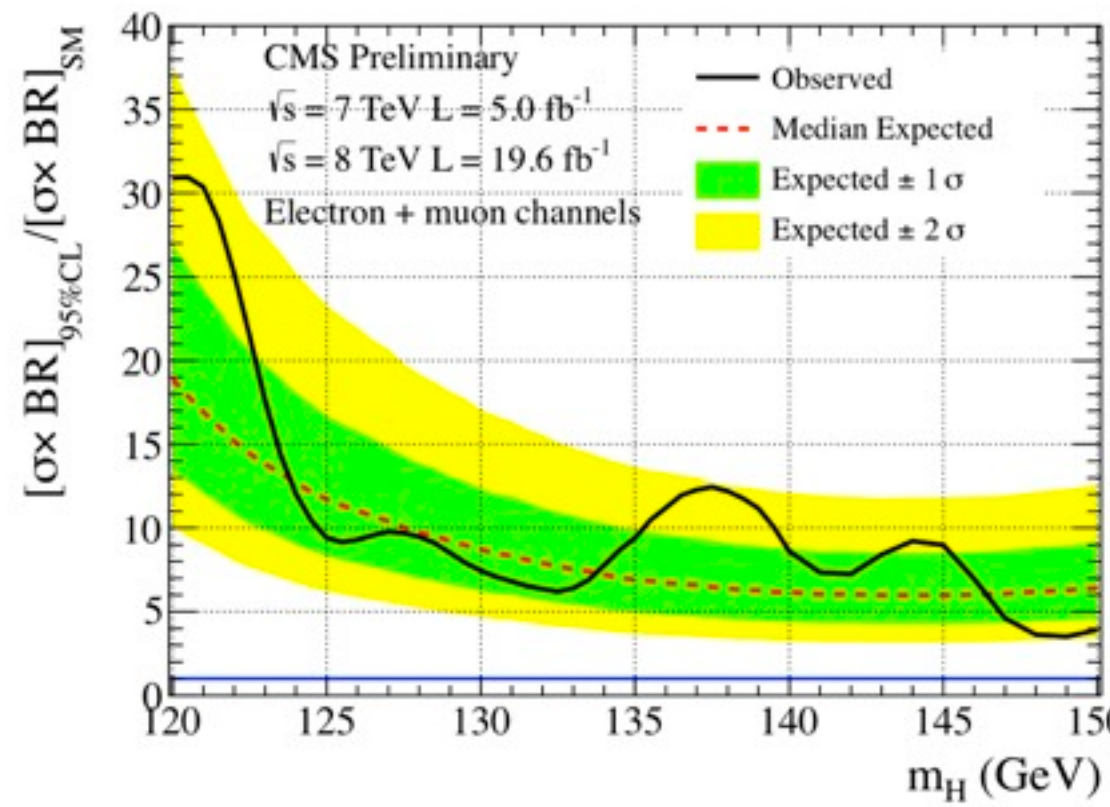
note: has not been updated with new diphoton analysis



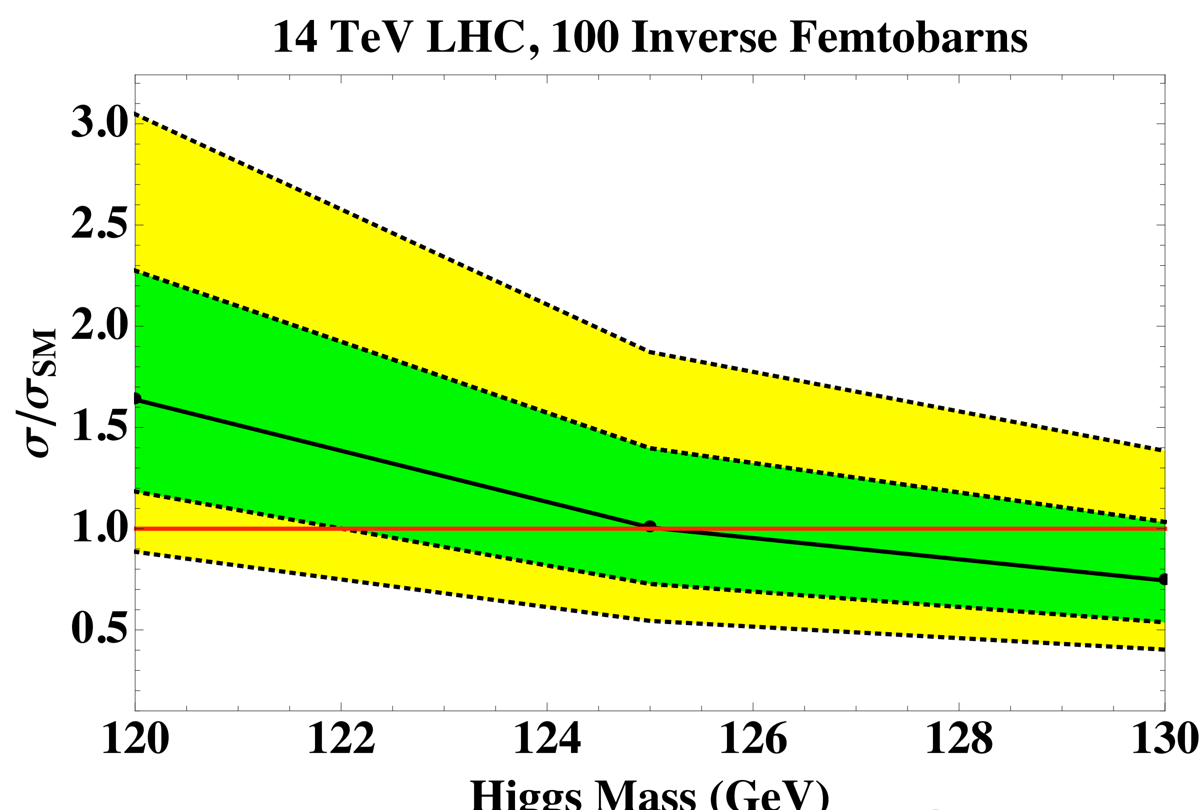
[Falkowski, Riva, Urbano '13]

$h \to Z\gamma$ (not yet)





Should eventually be able to probe SM rate using $\ell^+\ell^-\gamma$ channel

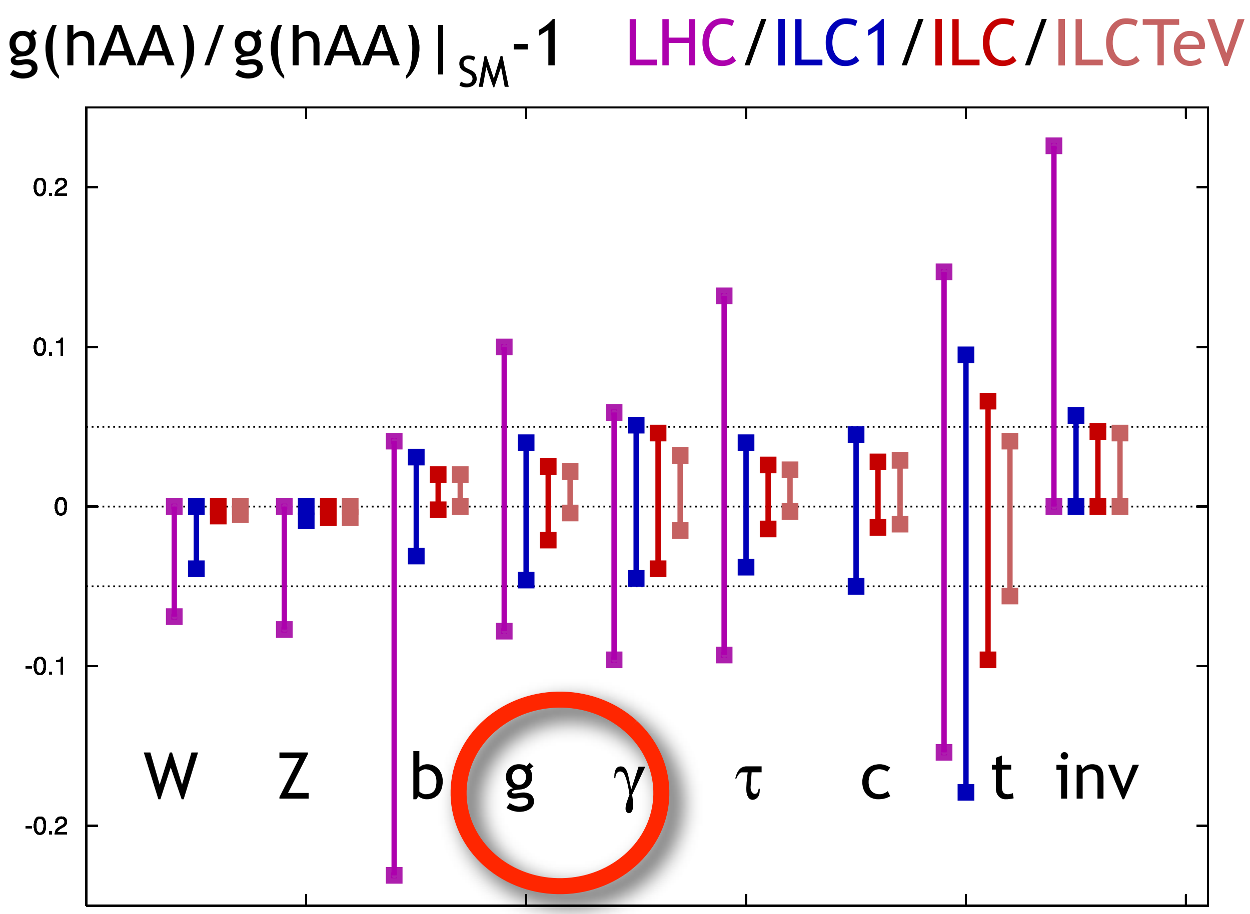


[Gainer, Keung, Low, Schwaller '12]

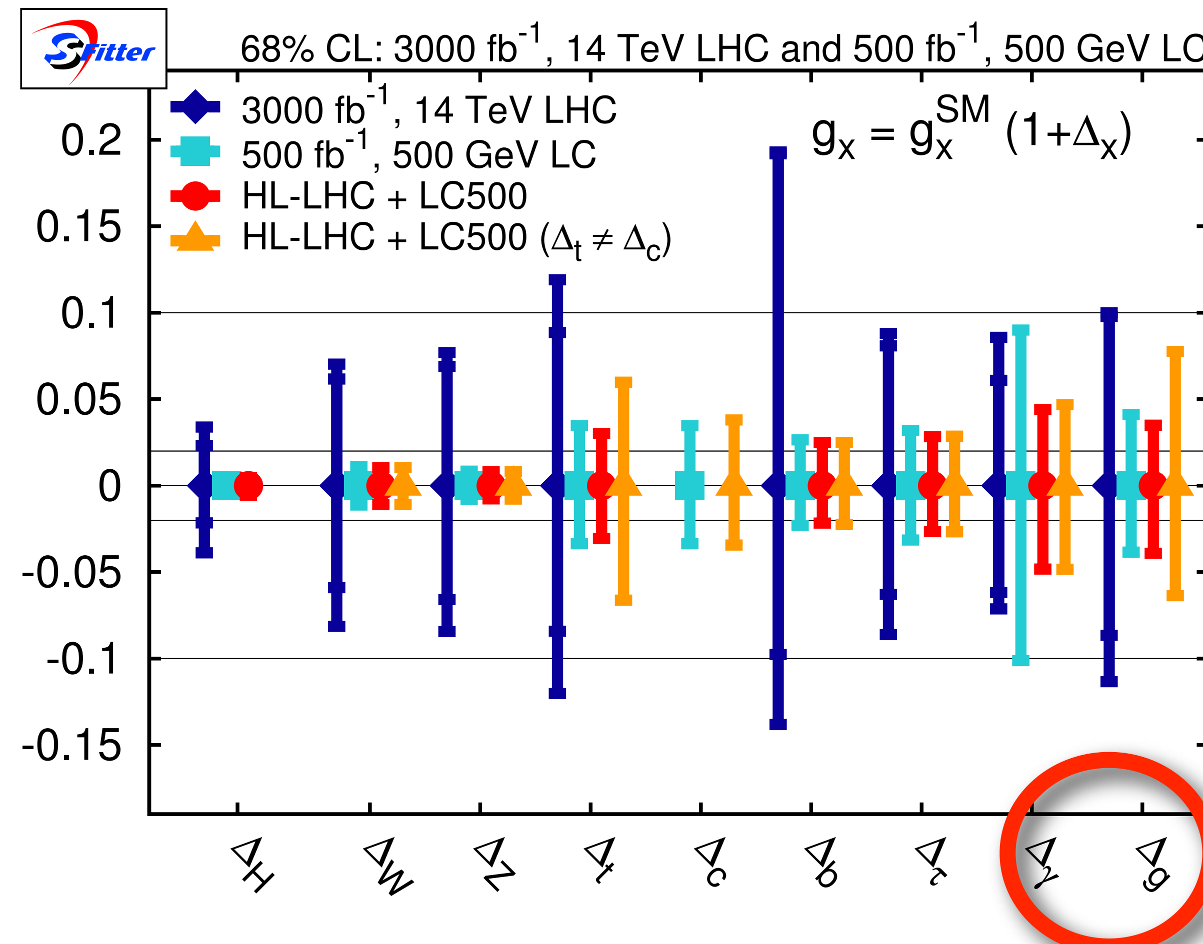
What level of precision can we hope to achieve?

$$g_{hAA} = (1+\Delta_A) g_{hAA}^{\mathrm{SM}}$$

[Peskin ’12]



[Klute et al. ’13]



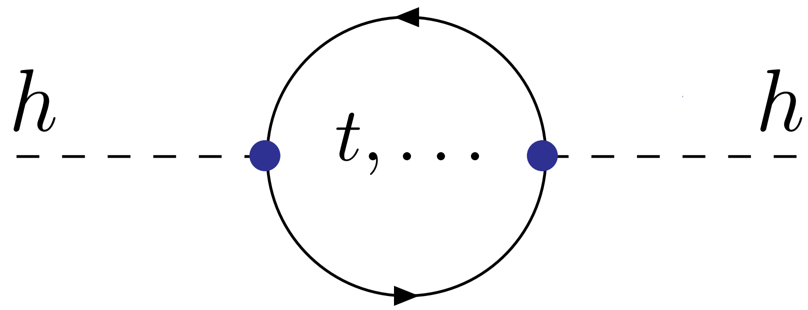
For $h\gamma\gamma, hgg$

LHC: ~ 10% level

Future facility: ~ few % level

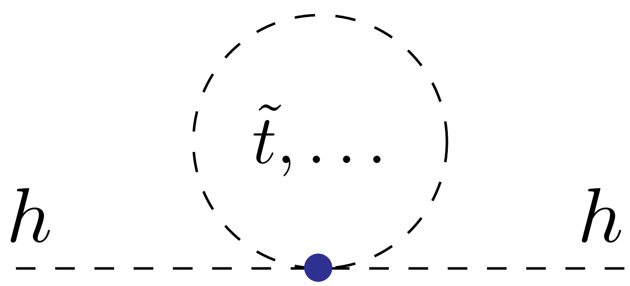
Noticeably absent is $h\gamma Z$; should be revisited!

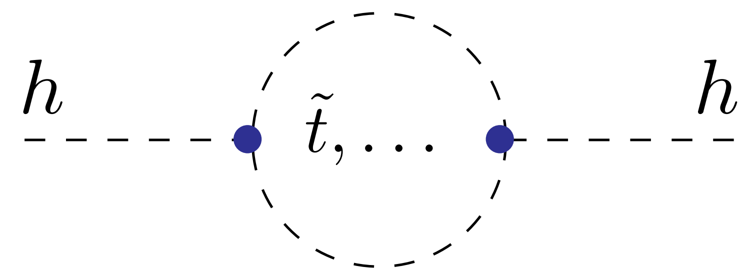
Naturalness

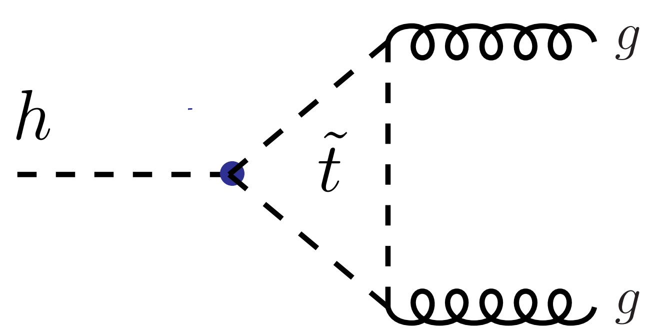


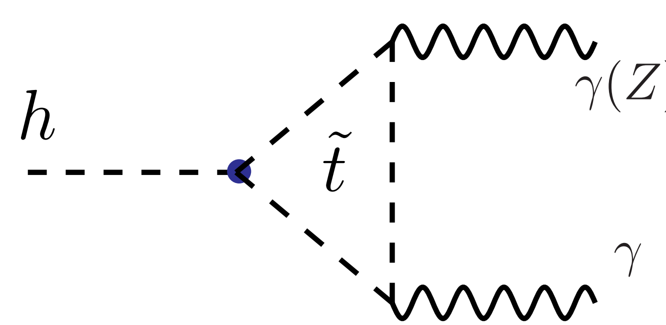
$$\Delta m_h^2 \sim \frac{3y_t^2}{8\pi^2}\Lambda_{\mathrm{UV}}^2$$

Motivates top-partners + ...



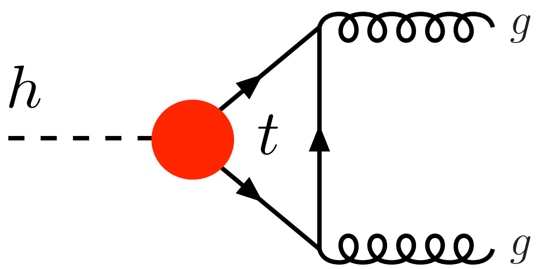


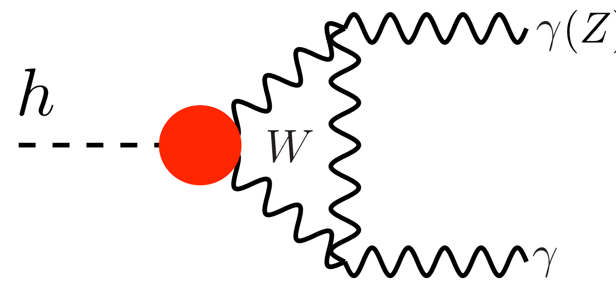




New loop-induced couplings

Tree level modifications ➡ loop level modifications





Extended scalar sector

$$\mathcal{L} \supset -\bar{u}_R Y_u Q H_u + \bar{d}_R Y_d Q H_d + \bar{e}_R Y_e L H_d + \text{h.c.}$$

MSSM
(Type 2 2HDM)

$$\frac{y_{htt}}{y_{htt}^{\text{SM}}} = \frac{\cos\alpha}{\sin\beta} \qquad \frac{g_{hVV}}{g_{hVV}^{\text{SM}}} = \sin(\beta-\alpha)$$

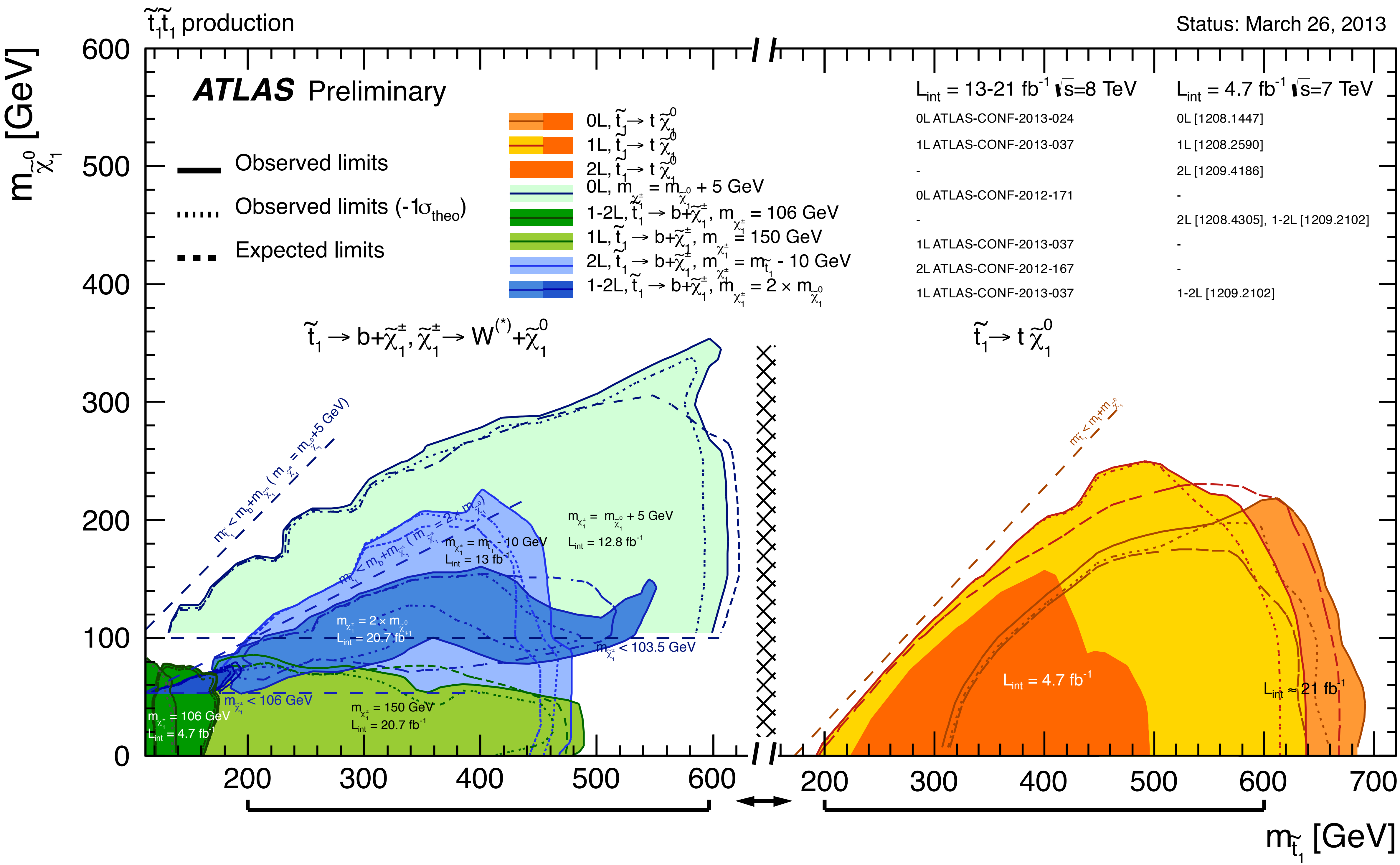
Compositeness

$$\Sigma = e^{i\sigma^a \pi^a / v}$$

$$\mathcal{L} = \frac{v^2}{4}\text{Tr}[(D_\mu\Sigma)^\dagger(D^\mu\Sigma)]\left(1+2a\frac{h}{v}+\dots\right) - m_i\bar{\psi}_{Li}\Sigma\left(1+c\frac{h}{v}+\dots\right)\psi_{Ri}$$

$$a, c \approx 1 + \mathcal{O}(v^2/f^2)$$

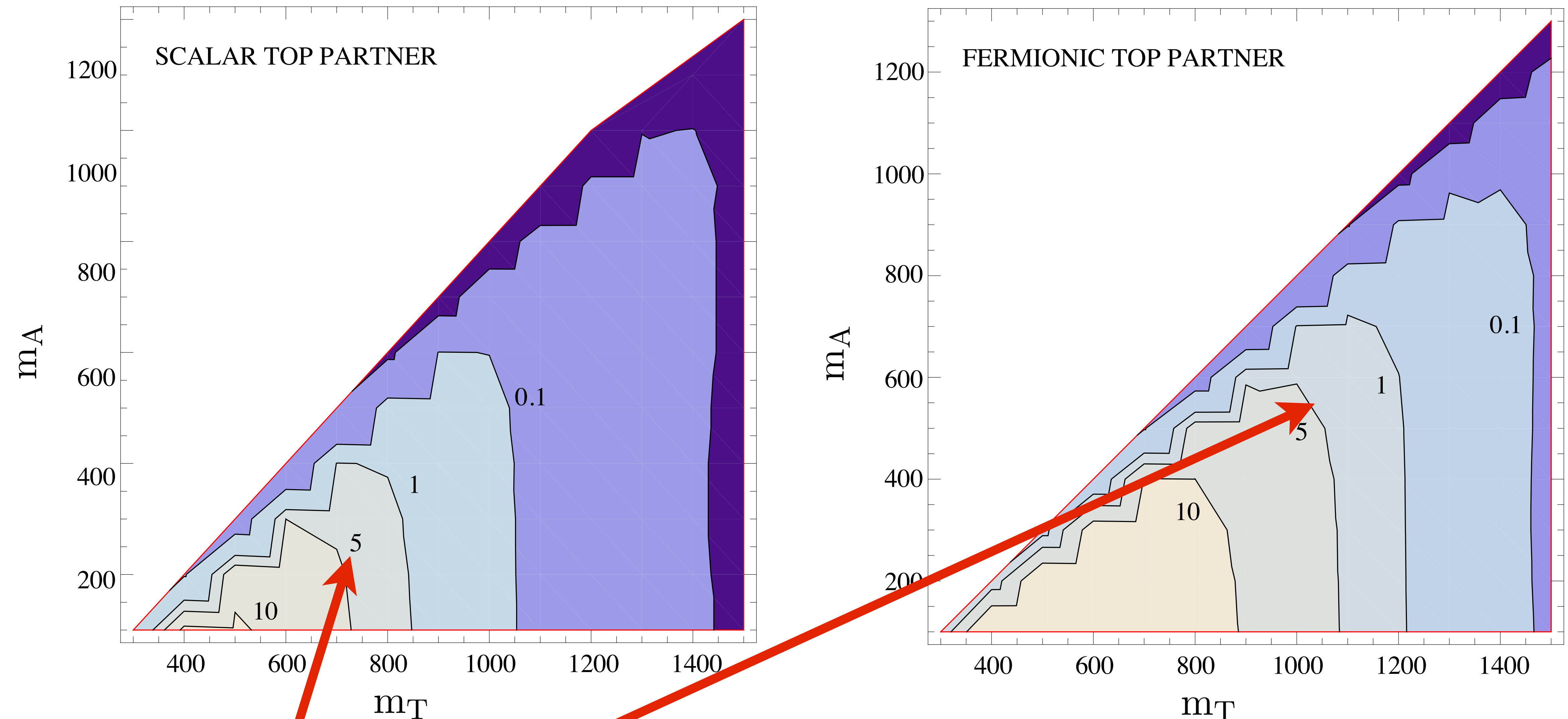
Current Stop limits



How high in $m_{\tilde{t}_1}$ can we go at LHC?

Reach for top partners

$pp \to t\bar{t} + \not{E}_T$ (Semi-leptonic)

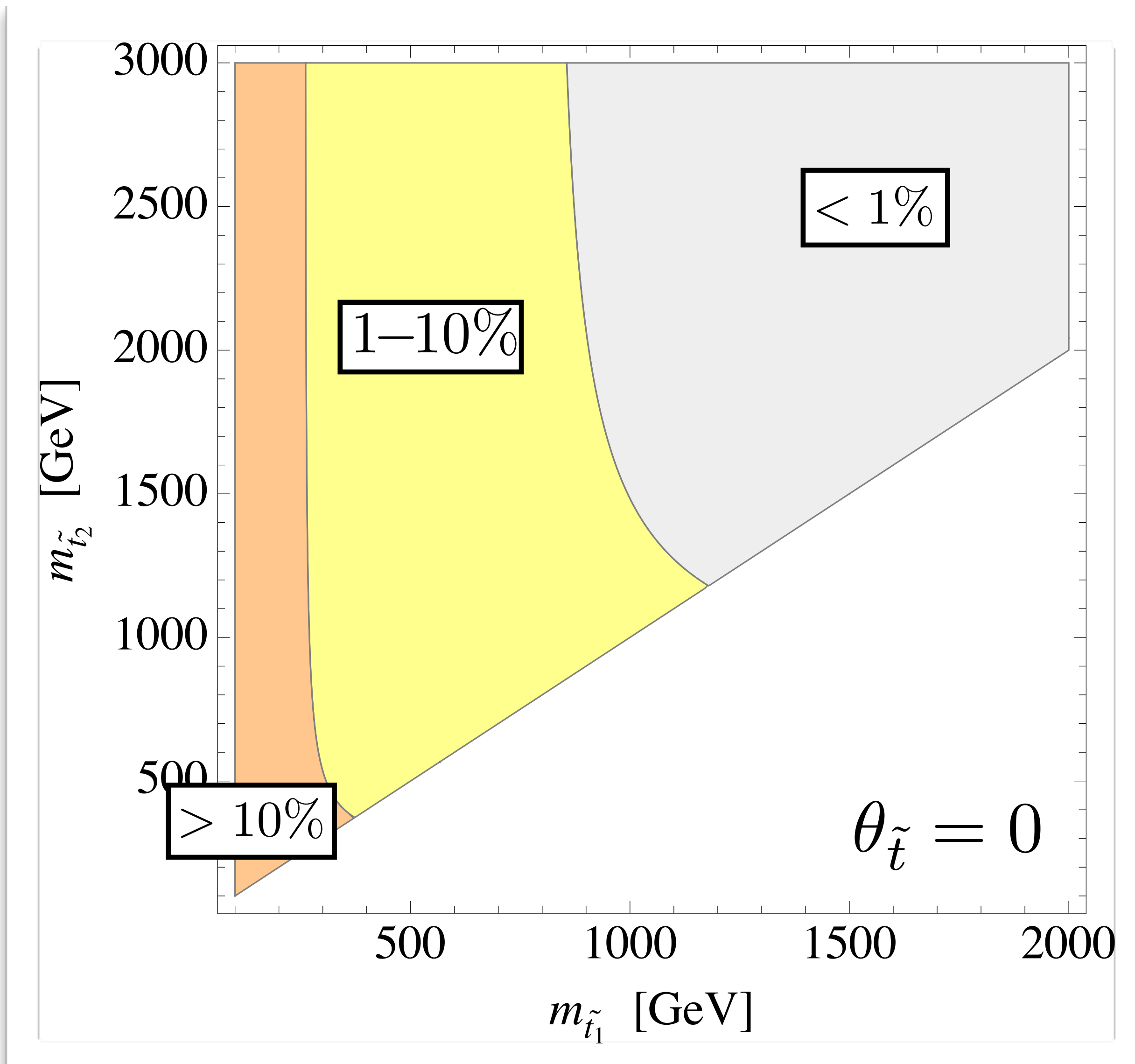


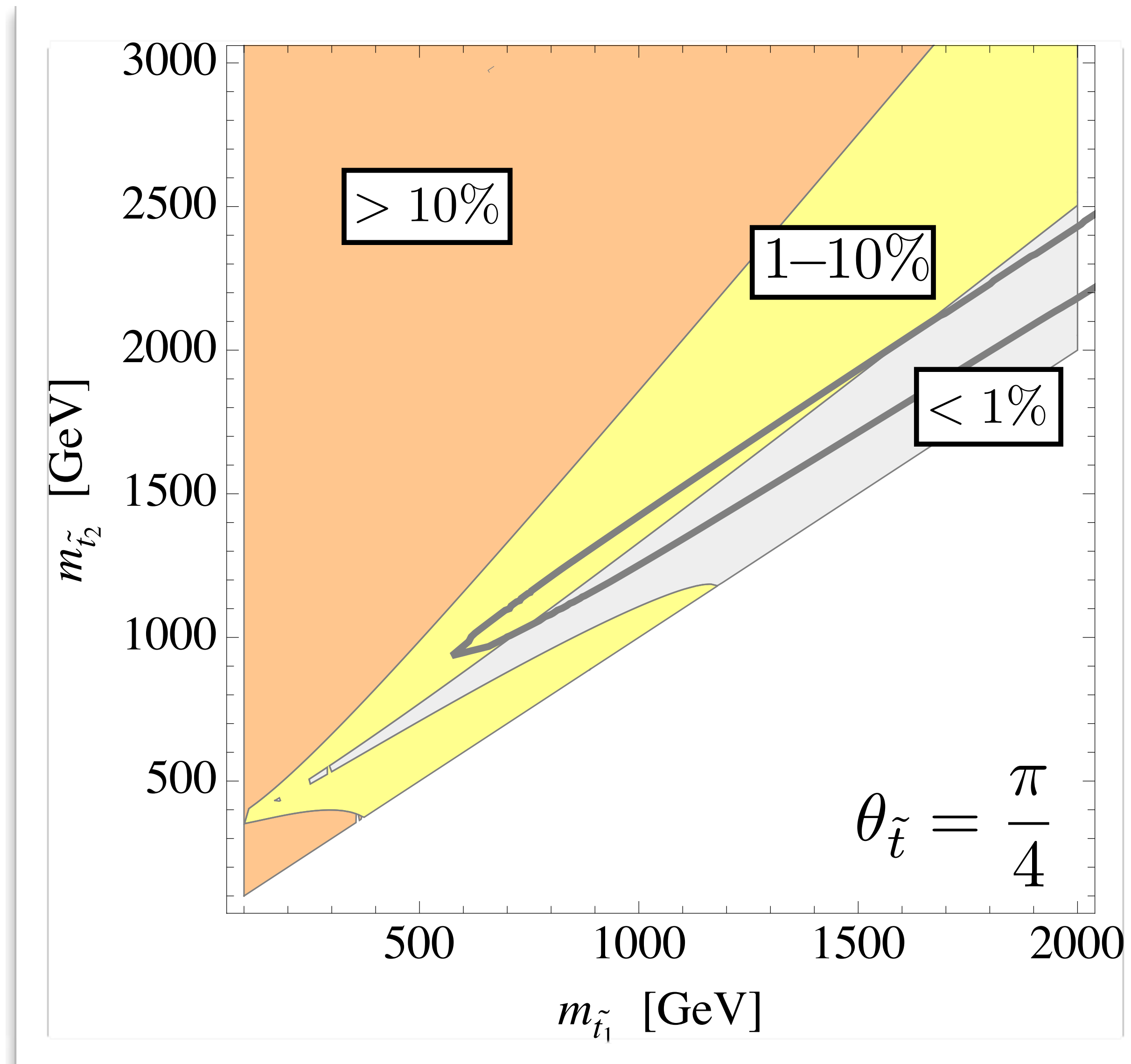
[Han, Mahbubani, Walker, Wang '08]

Difficult to go beyond ~ TeV in mass reach, model dependence
Can Higgs coupling measurements do better?

Stop

$$\Delta_g^{\tilde{t}} \simeq \frac{1}{4}\left[m_t^2\left(\frac{1}{m_{\tilde{t}_1}^2}+\frac{1}{m_{\tilde{t}_2}^2}\right)-\frac{1}{4}\left(\frac{m_{\tilde{t}_2}}{m_{\tilde{t}_1}}-\frac{m_{\tilde{t}_1}}{m_{\tilde{t}_2}}\right)^2\sin^2 2\theta_{\tilde{t}}\right]$$

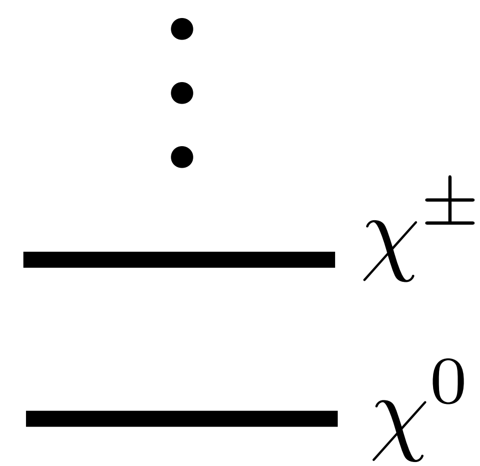




New charged/weakly interacting particles

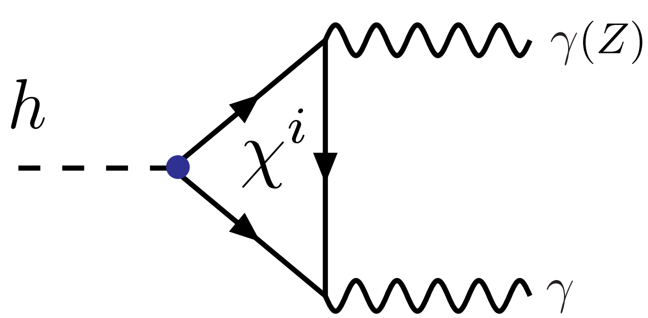
Can come along with Higgs, top partners in natural theories

Dark matter is neutral - may be part of an electroweak multiplet



New charged states

Can couple to the Higgs

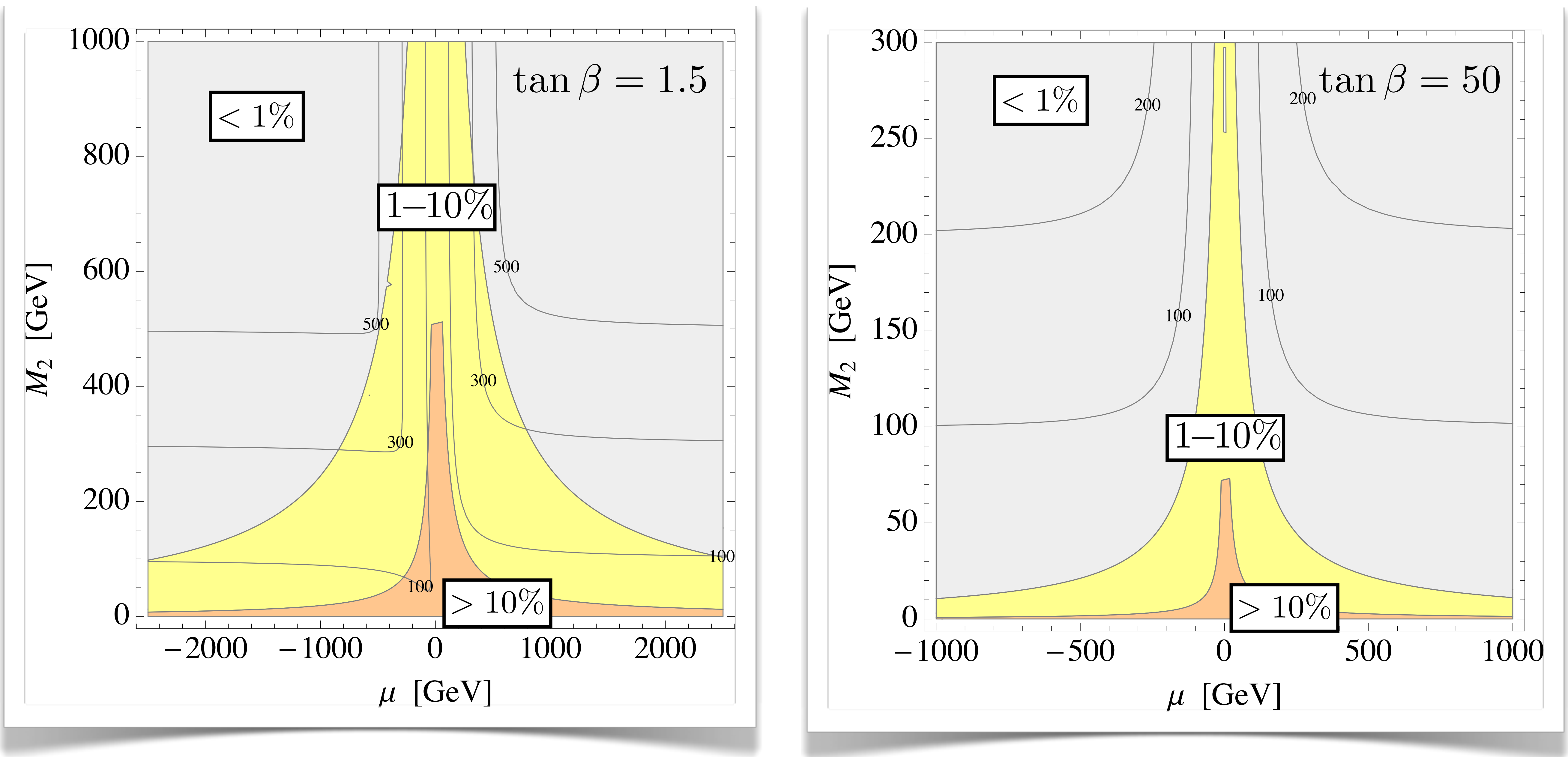


New loop-induced couplings

Difficult to probe directly at LHC

Chargino

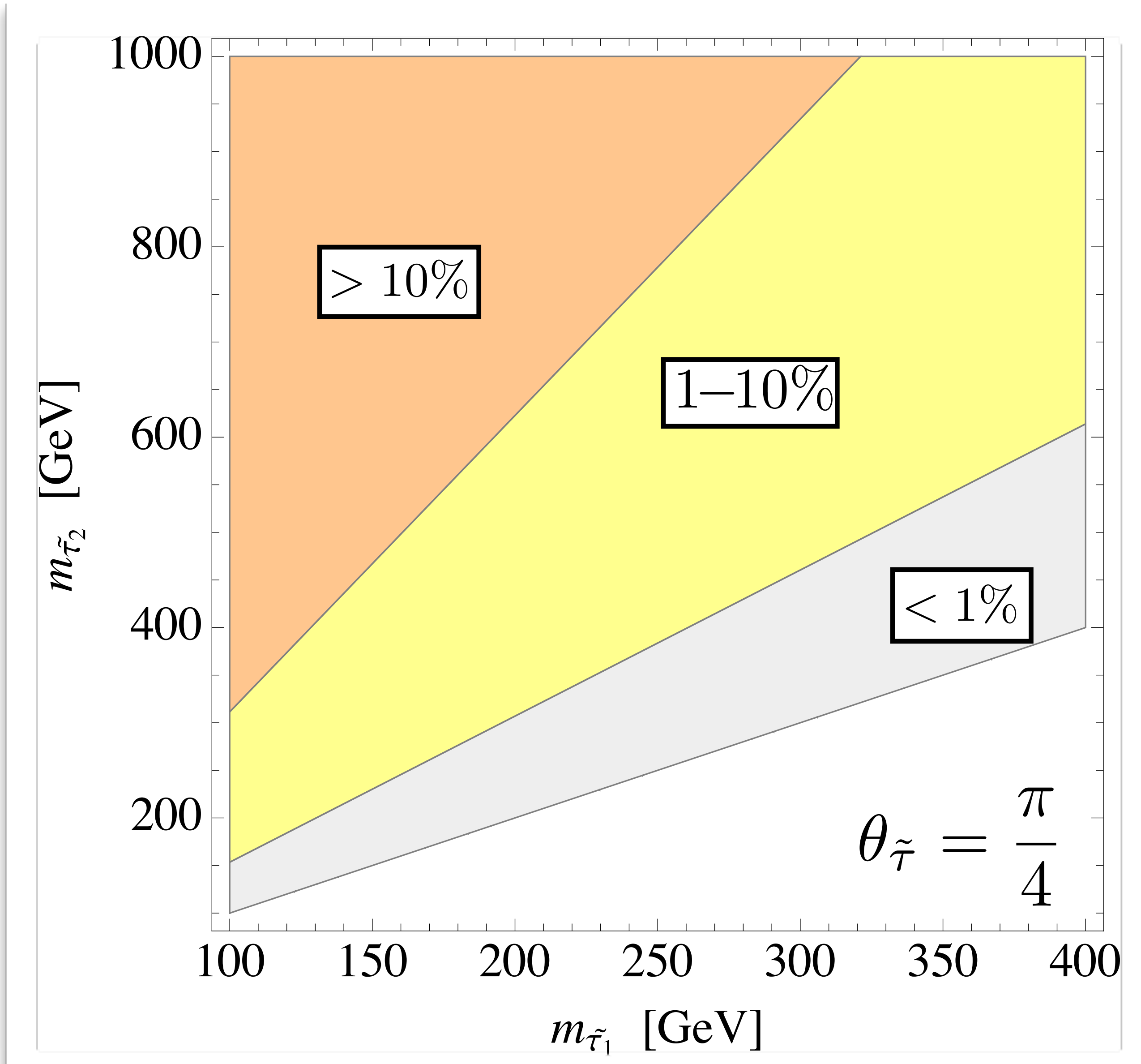
$$\Delta_\gamma^{\tilde{C}} \approx -\frac{8/3}{(-6.5)} \frac{m_W^2 \sin 2\beta}{M_2 \mu - m_W^2 \sin 2\beta}$$



Can probe 300 - 400 GeV charginos for small $\tan\beta$

Stau

$$\Delta_\gamma^{\tilde\tau} \simeq \frac{1}{12}\frac{1}{6.5}\left(\frac{m_{\tilde\tau_2}}{m_{\tilde\tau_1}} - \frac{m_{\tilde\tau_1}}{m_{\tilde\tau_2}}\right)^2 \sin^2 2\theta_{\tilde\tau}$$



Difficult to probe at LHC, see e.g.

[Carena, Gori, Shah, Wagner, Wang, '12]

Basic questions:

- Why worry about loop-induced couplings? Naturalness!
  - Ultimate reach of direct searches for top-partners and kin at LHC?
  - Size of deviations in Higgs couplings caused by such particles?
- Precision of LHC vs. future facility
  - Improvements in Higgs coupling measurements (new strategies)
  - Improved estimates for ultimate reach
  - What about $h\gamma Z$ at future facilities?
- Can (loop-induced) Higgs coupling measurements probe new states beyond direct reach of LHC? Yes!
  - More precise statements are needed...
  - What models? Which range of masses and couplings?
- How much sensitivity does a future facility buy?
  - Translate Higgs couplings studies to models